

# Performance Evaluation of IEEE 802.11 a, g Laboratory Open Point-to-Multipoint Links

J. A. R. Pacheco de Carvalho, H. Veiga, C. F. Ribeiro Pacheco, A. D. Reis

**Abstract**—The increasing importance of wireless communications, involving electronic devices, has been widely recognized. Performance is a crucial issue, leading to more reliable and efficient communications. Laboratory measurements were performed about several performance aspects of Wi-Fi (IEEE 802.11 a, g) Open point-to-multipoint links. Our study contributes to the performance evaluation of this technology, using new available equipments (V-M200 access points from HP and WPC600N adapters from Linksys). New detailed results are presented and discussed, namely at OSI levels 4 and 7, from TCP, UDP and FTP experiments: TCP throughput, jitter, percentage datagram loss and FTP transfer rate. Comparisons are made to corresponding results obtained for Open point-to-point links. Conclusions are drawn about the comparative performance of the links.

**Index Terms**—Wi-Fi; WLAN; IEEE 802.11a; IEEE 802.11g; Open Point-to-Multipoint Links; Wireless Network Laboratory Performance.

## I. INTRODUCTION

Contactless communications techniques have been developed using mainly electromagnetic waves in several frequency ranges, propagating in the air. Wi-Fi and FSO, whose importance and utilization have been recognized and growing, are important examples of wireless communications technologies.

Wi-Fi is a microwave based technology providing for versatility, mobility and favourable prices. The importance and utilization of Wi-Fi has been growing for complementing traditional wired networks. It has been used both in ad hoc mode and in infrastructure mode. In this case an access point, AP, permits Wi-Fi electronic devices to communicate with a wired based LAN through a switch/router. By this means a WLAN, based on the AP, is created. At the personal home level a WPAN allows personal devices to communicate.

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Point-to-point (PTP) and point-to-multipoint (PTMP) 2.4 and 5 GHz microwave links are used, with IEEE 802.11a, 802.11b, 802.11g and 802.11n standards [1]. The growing use of the 2.4 GHz band is leading to increasing interferences. Therefore, the 5 GHz band is receiving considerable attention, in spite of larger absorption and shorter ranges.

Nominal transfer rates up to 11 (802.11b), 54 Mbps (802.11 a, g) and 600 Mbps (802.11n) are specified. CSMA/CA is the medium access control. There are studies on wireless communications, wave propagation [2,3], practical implementations of WLANs [4], performance analysis of the effective transfer rate for 802.11b point-to-point links [5], 802.11b performance in crowded indoor environments [6].

Performance has been seen as a very important issue, resulting in more reliable and efficient communications. New telematic applications are specially sensitive to performances when compared to traditional applications. Requirements have been given [7].

Wi-Fi security is very important. Microwave radio signals travel through the air and can be easily captured by virtually everyone. Therefore, several security methods have been developed to provide authentication such as, by increasing order of security, WEP, WPA and WPA2. Several performance measurements have been made for 2.4 and 5 GHz Wi-Fi open [8-9], WEP [10-11], WPA [12-13] and WPA2 [14-15] links, as well as very high speed FSO [16]. It is important to investigate the effects of network topology, increasing levels of security encryption on link performance and compare equipment performance for several standards. In the present work new Wi-Fi (IEEE 802.11 a,g) results arise, using Open links, namely through OSI levels 4 and 7. Performance is evaluated in laboratory measurements of Open PTMP links using new available equipments. Comparisons are made to corresponding results obtained for Open PTP links.

In prior and actual state of the art, several Wi-Fi links have been investigated. Performance evaluation has been considered as a crucially important criterion to assess communications quality. The motivation of this work is to evaluate performance in laboratory measurements of Open PTMP links using new available equipments. Comparisons are made to corresponding results obtained for Open PTP links. This contribution permits to increase the knowledge about performance of Wi-Fi (IEEE 802.11 a,g) links [4-6]. The problem statement is that performance needs to be evaluated under several topologies. The solution proposed uses an experimental setup and method, permitting to monitor signal to noise ratios (SNR) and noise levels (N) and

measure TCP throughput (from TCP connections) and UDP jitter and percentage datagram loss (from UDP communications).

The rest of the paper is structured as follows: Section II is about the experimental details i.e. the measurement setup and procedure. Results and discussion are given in Section III. Conclusions are drawn in Section IV.

## II. EXPERIMENTAL DETAILS

The measurements used a HP V-M200 access point [17], with three external dual-band 3x3 MIMO antennas, IEEE 802.11 a/b/g/n, software version 5.4.1.0-01-9867 and a 100-Base-TX/10-Base-T Allied Telesis AT-8000S/16 level 2 switch [18]. Two PCs were used having a PCMCIA IEEE.802.11 a/b/g/n Linksys WPC600N wireless adapter with three internal antennas [19], to enable (three-node) PTMP links to the access point. In every type of experiment, interference free communication channels were used (ch 36 for 802.11a; ch 8 for 802.11g). This was checked through a portable computer, equipped with a Wi-Fi 802.11 a/b/g/n adapter, running NetStumbler software [20]. No encryption was activated in the AP and the wireless adapters of the PCs. The experiments were made under far-field conditions. No power levels above 30 mW (15 dBm) were required, as the wireless equipments were close.

A versatile laboratory setup has been planned and implemented for the PTMP measurements, as shown in Fig. 1. It involves two wireless links to the AP. At OSI level 4, measurements were made for TCP connections and UDP communications using Iperf software [21]. For a TCP connection, TCP throughput was obtained. For a UDP communication with a given bandwidth parameter, UDP jitter and percentage loss of datagrams were determined. Parameterizations of TCP packets, UDP datagrams and window size were as in [12]. One PC, with IP 192.168.0.2 was the Iperf server and the other, with IP 192.168.0.6, was the Iperf client. Jitter, which represents the smooth mean of differences between consecutive transit times, was continuously computed by the server, as specified by the real time protocol RTP, in RFC 1889 [22]. Another PC, with IP 192.168.0.20, was used to control the settings in the AP.

The scheme of Fig. 1 was also used for FTP measurements, where FTP server and client applications were installed in the PCs with IPs 192.168.0.2 and 192.168.0.6, respectively.

The server and client PCs were HP nx9030 and nx9010 portable computers, respectively, running Windows XP Professional. They were configured to optimize the resources allocated to the present work. Batch command files have been re-written to enable the new TCP, UDP and FTP tests.

The results were obtained in batch mode and written as data files to the client PC disk. Every PC had a second network adapter, to permit remote control from the official IP University network, via switch.

## III. RESULTS AND DISCUSSION

The wireless network adapters of the PCs were manually configured for each standard IEEE 802.11 a, g with typical nominal transfer rates (6, 9, 12, 18, 24, 36, 48, 54 Mbps). For every fixed transfer rate, data were obtained for comparison of the laboratory performance of the PTMP and PTP links at OSI levels 1 (physical layer), 4 (transport layer) and 7 (application layer) using the setup of Fig. 1. For each standard and every nominal fixed transfer rate, an average TCP throughput was determined from a set of experiments. This value was used as the bandwidth parameter for every corresponding UDP test, resulting in average jitter and average percentage datagram loss.

At OSI level 1, signal to noise ratios (SNR, in dB) and noise levels (N, in dBm) were measured. The measured data were similar for both experiment types. Typical values are shown in Fig. 2.

The main average TCP and UDP results are summarized in Table I, both for PTMP and PTP links. The statistical analysis, including calculations of confidence intervals, was carried out as in [23].

In Figs. 3 and 4 polynomial fits were made (shown as  $y$  versus  $x$ ), using the Excel worksheet, to the 802.11a, g TCP throughput data for PTMP and PTP links, respectively, where  $R^2$  is the coefficient of determination. It gives information about the goodness of fit. If it is 1.0 it means a perfect fit to data.

It was found that, on average, the best TCP throughputs are for 802.11 a and PTP links (15.0+-0.5 Mbps). In Figs. 5-8, the data points representing jitter and percentage datagram loss were joined by smoothed lines.

It was found that, on average, jitter performances are better for PTP (2.2+- 0.1 ms and 3.2+- 0.9 ms for 802.11a and 802.11g, respectively) than for PTMP links (2.6+- 0.2 ms and 3.8+- 0.7 ms for 802.11a and 802.11g, respectively).

Concerning average percentage datagram loss, performances were generally found as better for PTP than for PTMP links. In comparison to PTP links, TCP throughput, jitter and percentage datagram loss were generally found to show performance degradations for PTMP links, where the processing requirements for the AP are higher so as to maintain links between PCs.

At OSI level 7 we measured FTP transfer rates versus nominal transfer rates, configured in the wireless network adapters of the PCs, for the IEEE 802.11a, g standards. The result for every measurement was an average of several experiments involving a single FTP transfer of a binary file with a size of 100 Mbytes. The FTP results show the same trends found for TCP throughput.

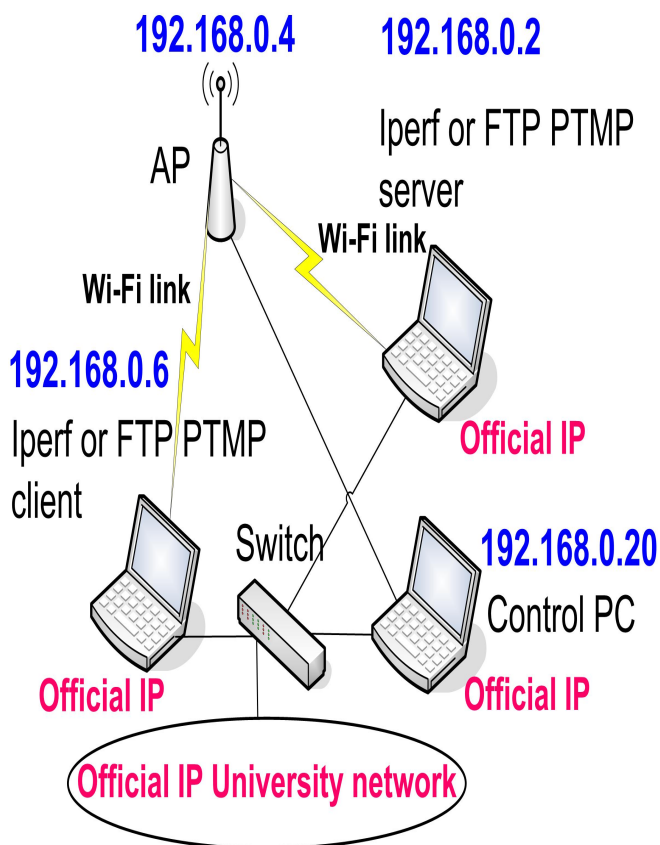


Fig. 1- Laboratory setup scheme.

TABLE I  
 AVERAGE WI-FI (IEEE 802.11 A, G) OPEN RESULTS; PTMP; PTP

Exp type	PTMP		PTP	
	802.11a	802.11g	802.11a	802.11g
Parameter / IEEE standard				
TCP throughput (Mbps)	8.1 +/-0.2	6.5 +/-0.2	15.0 +/-0.5	13.9 +/-0.4
UDP-jitter (ms)	2.6 +/-0.2	3.8 +/-0.7	2.2 +/-0.1	3.1 +/-0.9
UDP-% datagram loss	1.7 +/-0.5	1.3 +/-0.1	1.4 +/-0.1	1.5 +/-0.1

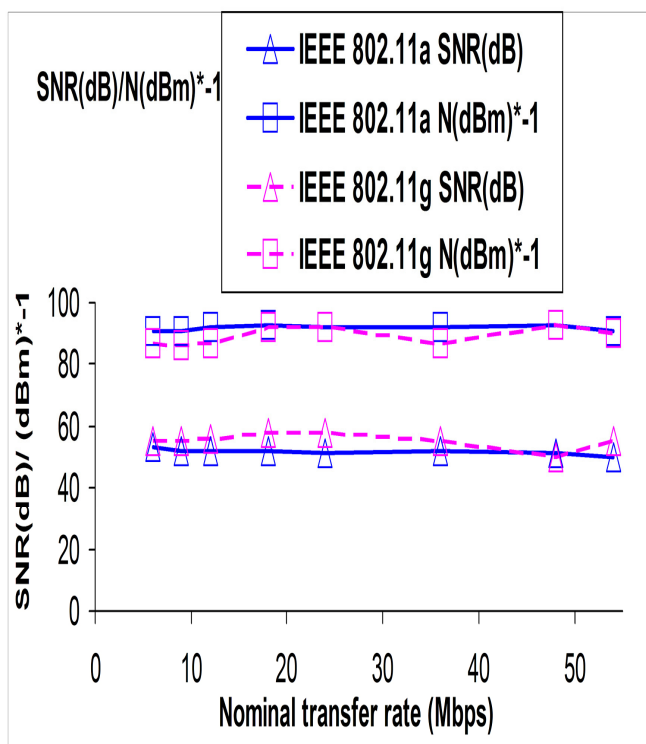


Fig. 2- Typical SNR (dB) and N (dBm). Open PTMP.

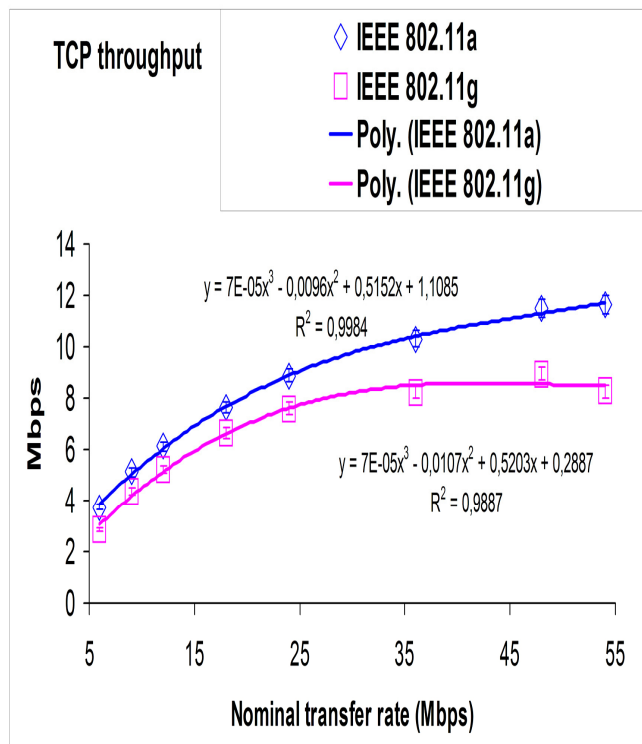


Fig.3- TCP throughput (y) versus technology and nominal transfer rate (x). Open PTMP.

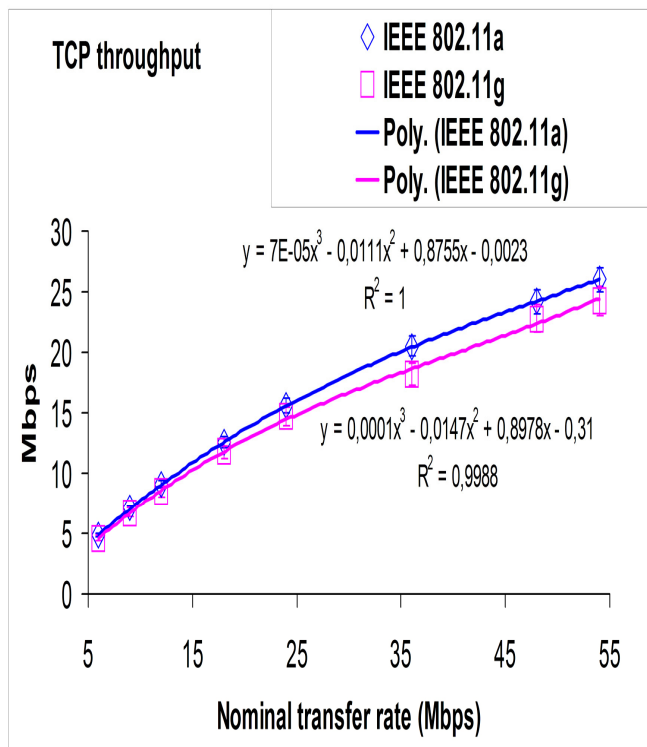


Fig. 4- TCP throughput (y) versus technology and nominal transfer rate (x). Open PTP.

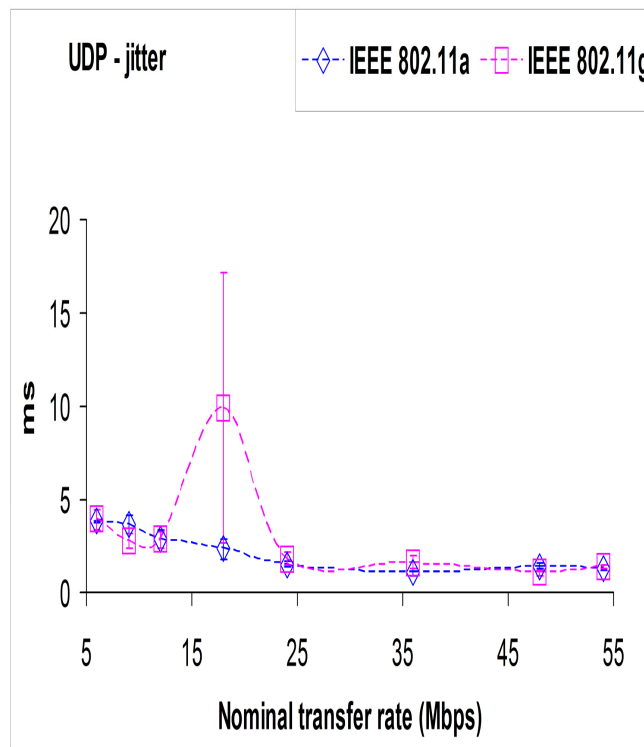


Fig. 6- UDP – jitter results versus technology and nominal transfer rate. Open PTP.

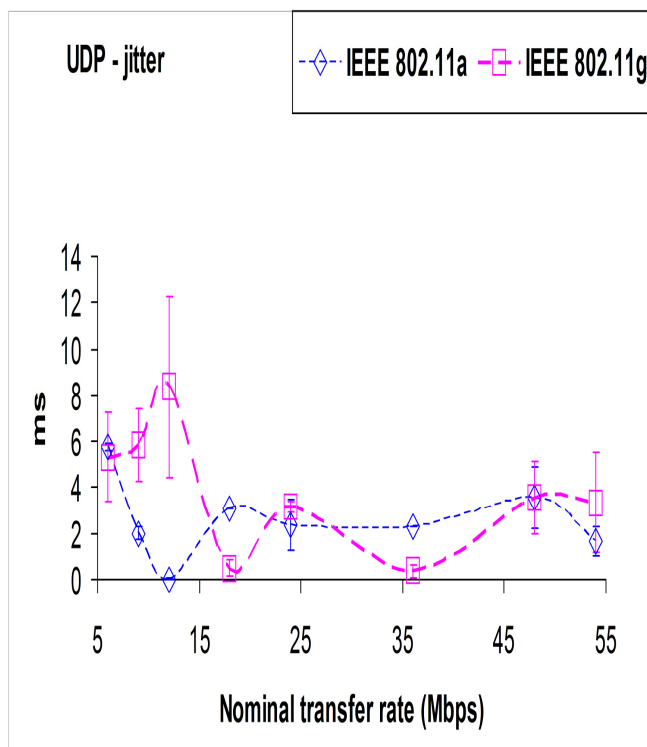


Fig. 5- UDP – jitter results versus technology and nominal transfer rate. Open PTMP.

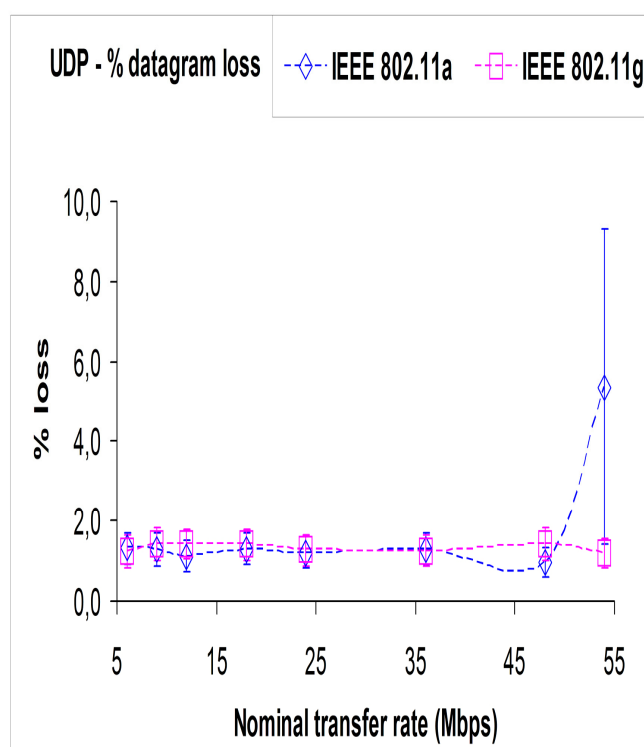


Fig. 7- UDP – percentage datagram loss results versus technology and nominal transfer rate. Open PTMP.

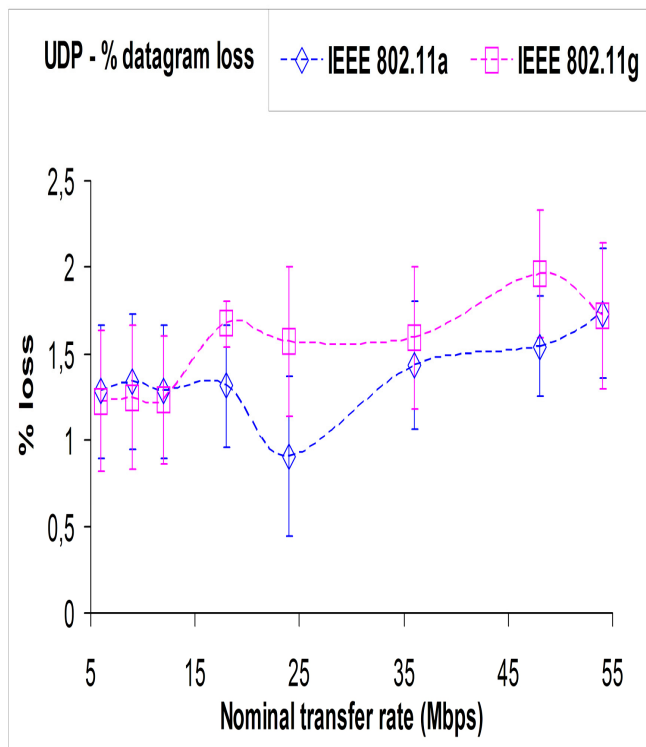


Fig. 8- UDP – percentage datagram loss results versus technology and nominal transfer rate. Open PTP.

#### IV. CONCLUSION

In the present work a versatile laboratory setup arrangement was planned and implemented, that permitted systematic performance measurements of new available wireless equipments (V-M200 access points from HP and WPC600N adapters from Linksys) for Wi-Fi (IEEE 802.11 a, g) in Open PTMP links.

Through OSI layer 4, TCP throughput, jitter and percentage datagram loss were measured and compared for each standard to corresponding results obtained for Open PTP links. In comparison to PTP links, TCP throughput, jitter and percentage datagram loss were generally found to show performance degradations for PTMP links, where the AP experiments higher processing requirements so as to maintain links between PCs.

At OSI layer 7, FTP performance results have shown the same trends found for TCP throughput.

Further performance studies are planned using several equipments, topologies, security settings and noise conditions, not only in laboratory but also in outdoor environments involving, mainly, medium range links.

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